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THESIS

DISTANCE PERCEPTION AND VISUALIZATION USING VIRTUAL ENVIRONMENTS

by

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September 2000

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DISTANCE PERCEPTION AND VISUALIZATION USING VIRTUAL ENVIRONMENTS

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The studies in this thesis include experiments in training transfer, metric and visual feedback, field of view within the visual display, and cognitive relationships with distance perception. Participants were tested to show positive training transfer, retention of training, and organizational skills. Participants were trained to judge the distance perception in the in-depth plane, given a distance in a frontoparallel plane and also trained to judge perceived distances from themselves to an object. Experiment one shows that a positive training transfer exists from the virtual to the real world and visa versa. Experiments two and three show that perceptual feedback gives more information than metric feedback. Experiment four shows that between 30 – 60 degree geometric field of view setting should be used for optimal performance on distance estimation tasks using an HMD with 60-degree optical FOV. Experiment five shows that there is no correlation between how well participants organize symbols and how well they can be trained to judge distances. Experiments also confirm that as distances increased so did the amount of error.

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LIST OF ACRONYMS

3D	Three Dimensional
ANOVA	Analysis of Variance
CRT	Cathode Ray Tube
DOD	Department of Defense
DON	Department of the Navy
FOV	Field of View
GFOV	Geometric Field of View
HMD	Head Mounted Display
LCM	Liquid Crystal Modulator
MOVES	Modeling, Virtual Environments and Simulations Academic Group, Naval Postgraduate School, Monterey, CA.
PFOV	Physical Field Of View
PLZT	Lead Lanthanum Zirconate Titanate Ceramic Wafers

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I. INTRODUCTION

Training programs have become very time consuming and expensive in the real world, and in the case of combat training, often impossible to simulate. Yet, throughout the world there has been an increase in the amount of combat missions for which troops need to be prepared. The United States Department of Defense Directive 1430.13 has authorized the use of training simulators to increase the readiness of its troops. In regards to this there have been major claims about the efficacy of virtual environments for both training and skill improvement (Winn, 1998; Seidel and Chatelier, 1997). In most cases these programs require the trainee to form a mental image of the environment and apply it to the real world. There is some evidence that distortion of spatial distances in virtual environments leads to distorted images of real world perceived distances (Witmer and Kline, 1998). Distortions in virtual environments are usually caused by the lack of, or misrepresentations of, certain distance cues.

A. MOTIVATION

A good example of this phenomenon in the real world is onboard a typical aircraft carrier. An aircraft carrier has a large flat deck (the flight deck) that sits about 50 yards above the waterline, with an island structure that sits in the middle and to the right-hand side of the ship. Atop the island is the bridge. The bridge's field of view is hindered by the flight deck, so much so that from the bridge a person cannot see anything from the side of the ship out to the point where the flight deck and bridge point of views meet (Figure 1).

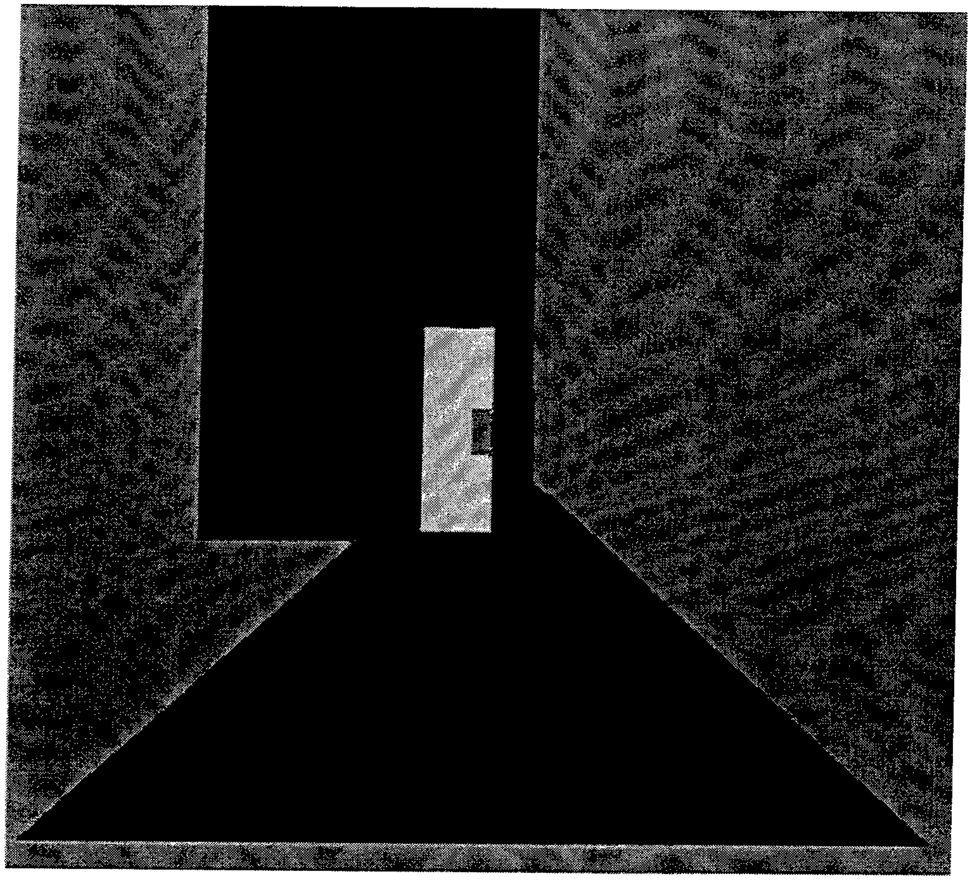

Figure 1. The Blind Spots on a Typical Aircraft Carrier from the Bridge

The current solution to this is to have a person with a radio stand at the end of the flight deck and look down into this blind spot. The question most often asked of this person is "What's the distance to that object?" The observer has to look down about 50 yards then out the distance to the object. This distance down to the water changes from ship design to ship design. For example, a Kitty Hawk class would have a shorter distance to the water than a Nimitz class. This task of determining distances is a very difficult task since no training is given. How does one acquire this skill? The question of distance perception affects all aspects of daily life, from the operation of vehicles to the simple feat of picking up a pencil from a desk. In general, the question is what makes

distance perception in a virtual environment different from the real world? This thesis presents a series of studies addressing this issue.

B. APPROACH

From the world, our senses are filled with input. Interpreting all this input lets the mind build a picture of how it fits into that world. From this picture comes a feeling of presence, which is the point where the mind places itself from the input it is given. The mind takes this input in the form of time, light, shapes, sounds, and even past experiences. A good virtual world will build a coherent feeling of presence for the mind to put together and interpret. Distance perception is part of this presence/picture. Each experiment in this thesis has been designed to remove, as much as possible, all the distance cues, except what is being studied in that experiment.

C. THESIS OUTLINE

Five different experiments were performed in distance perception for this thesis. Experiment one was the pilot study and looked at the effect of training transfer using an exocentric distance-matching task. This experiment showed that a positive training transfer exists from the virtual to the real world and visa versa and that the basic design used throughout the thesis has a positive training effect. Experiments two and three looked at training retention and perceptual versus metric feedback using egocentric distances. These experiments showed that for this setup there was an inverse of training retention from what was expected and that perceptual feedback gave more information than metric feedback. Experiment four used the same exocentric distance-matching task as experiment one. The question here is what is the optimal horizontal Field Of View

(FOV) for the 60-degree FOV Head Mounted Display (HMD). This experiment showed that between 30 – 60 degree field of view setting should be used for optimal performance on distance estimation tasks using an HMD set to 60 degree FOV setting. Forty-eight degrees was used in experiment five to create the most real world viewing experience. Experiment five also used an exocentric distance-matching task with perceptual and metric feedback. A cognitive task was added to see if participants' ability to organize symbols affected distance perception training. This experiment proved that there was no correlation between how well participants organized and how well they could be trained to judge distances. Participants probably used different resources for the different tasks. This experiment also confirmed that as distances increased so did the amount of error by a factor of three.

II. BACKGROUND

A. DISTANCE PERCEPTION

Distance perception is a combination of distance estimation and depth perception. The ability to judge distance accurately is essential in the real world. Navigation, driving, flying, and combat skills all depend upon this ability. The relationship that exists between these elements has been well documented and modeled by Steven's power law ($\delta = k*d^n$). The actual distance (d), the judged distance (δ), the modulus (k)[1], and the exponent (n), all depend on the nature of the judgment (Stevens, 1975). This allows the use of a measure of accuracy modeled by (percent overestimation equation = $100(\delta - d)/d$). As this formula shows, any absolute accuracy in distance judgments must account for both modulus and exponent estimates (Montello, 1991). To date, the greatest amount of work with distance perception has been done using stationary objects and stationary viewing points. Ellis contends that true distance perception can't be perceived unless motion is involved (Ellis, Menges, Jacoby, Adelstien, and McCandles, 1997), thus leading to the work done by Crvarich in understanding distance perception (Crvarich,1999). Distance is perceived in two ways - monocular and binocular (stereo).

B. MONOCULAR AND STEREO VISION

Monocular perception provides the same view to each eye. This view helps the participant to determine such things as textures, motion, and size. Most depth cues are additive and some are more powerful than others with some being cumulative; this may produce conflicting depth information. The following cues effect distance perception:

[1] unit dependent scale factor

- Colors - bright colored objects that have the same physical dimensions, as darker colored objects, will appear closer than the dark colored object.
- Textures - closer objects have greater detail, further objects blur as the object moves away.
- Image size - if the general size of a person, which is known, is compared to a bowling ball, which is the same size as the person, the assumption is the bowling ball is closer.
- Interposition - objects in front of others appear to be closer.
- Perspective - objects that are far away appear hazy and bluish. Blue has shorter wavelength thus it travel, further in an atmosphere than other colors.
- Shading - light from a light source, fades at greater distances making objects darker.

Physical changes to objects in the world affect how they are seen. The two major effects are binocular disparity and motion parallax. Binocular disparity is the difference in the images projected on the left and right eye. It is modeled in computer graphics by displaying two different images projected off the center axis of a perspective projection. Motion parallax is defined by the movement of your head from side to side or the movement of the background against two objects. Distance is determined by the relative speed of the objects against the background. Objects that are closer move faster (McAllister, 1999).

Binocular perception provides each eye with a view offset referred to as "Binocular Disparity", thus creating the condition called stereopsis (Crvarich, 1999).

> … that looks like somebody looking at you cross-eyed. Now, look back at him cross-eyed. Cross your eyes far enough that you fuse the image from the right eye with the image from the left eye. Now, you see three Cyclops, that trio of one-eyed gods of ancient times. The one in the middle is seen stereoscopically: His eye is in front, and his pupil is now seen to actually be a retina, located far in the back of his head.

The study of stereopsis, and discovery of stereopsis blindness, was the major work of the one-time radar engineer, Bela Julesz of Bell Telephone Laboratories (now Lucent Technologies). His study of seeing through snow on radar screens led to his development of the random-dot stereogram as a research tool. He named his field of study "Cyclopean perception" because it deals with brain activity in the visual cortex, located in the back of the brain where information from the two eyes is combined and processed. Julesz called this "the cyclopean retina (Unknown, 1999)."

Physiological depth cues are broken down into two different types: accommodation and convergence. Accommodation is the physical change to the lens thickness due to tension by the ciliary's muscle. This allows the eyes to focus on a three dimensional (3D) scene. Convergence is the inward rotation of the eyes to converge on an object. This is often called "free-viewing". In order to view 3D stereo images you must have two eyes that work together as a coordinated team. A portion of the population exists, less than five percent of the total, that has severe visual disabilities making stereovision extremely difficult or impossible. This group includes those who have lost an eye or those with severe amblyopia, lazy eye, or strabismus, where the eye turns -- "crossed eyes" or "wall-eye". Strabismus is defined as a condition where the two eyes are not aimed in the same common direction. Strabismus can have many different

causes, but the most common cause is simply that the person has never learned to use the two eyes together at the same time. A child is born with two eyes, but teaming them together is a learned skill, perceptual motor skill, or developmental skill. A child learns this skill similarly to the way he learns to walk and to talk. From a developmental standpoint, a child first learns to use the two halves of the body together before he learns to use the two eyes together and, developmentally, a child first learns control of the large muscles of the body before he learns control of the fine muscles of the eyes. If both eyes are pointing in the same direction, the child can experience, what is termed, single binocular vision, stereoscopic vision, or binocular depth perception. However, if the two eyes are not pointing in the same direction, a child may experience double vision, such as in the cases of strabismus, amblyopia, deviation of the eye, and deviating eyes. Since seeing double is an intolerable sensation, most children will learn to suppress, turn off, or ignore the visual impulses coming in from the deviating eye. This generally results in a deterioration or reduction of vision in the eye that is being turned off: the deviating eye. Since clear vision is also a learned skill, visual acuity may not develop properly in the deviating eye. When one eye does not develop adequate visual skills, the visual condition is termed amblyopia, or lazy eye. (Hodges, 1999)

1. Stereo Vision Technology

Computer Stereo Vision is an image created on a 3D coordinate system, then displayed as a parallel or perspective projection onto a flat CRT screen and usually viewed with special glasses. Human stereo vision probably evolved as a means of survival. With stereo vision, objects can be seen that are in relation to the bodies with much greater precision, especially when those objects are moving toward or away from

the body. Little bits of solid objects are seen without moving the head and a person can even perceive or measure "empty" space with their eyes and brain. Stereo vision is used to see *an* object that is viewed in the real world. The right eye and the left take in an image. The brain works like a supercomputer. It takes the two images from the separate eyes and combines them into an image that can be understood and identified (Capps, 1999). This is accomplished with a computer in the real world in two different ways: Time Multiplexed and Time Parallel.

Time Multiplexed uses field sequential signals so that different views are shown, on a CRT, for each eye. Devices used are

- PLZT(lead lanthanum Zirconate Titanate ceramic wafers), electro optical shutters, only transmit 15 – 17 percent of light from a CRT. Light passes through a front vertical polarizer when voltage applied the light is rotated 90 degrees to pass through a rear horizontal polarizer. This can be in the form of glasses that are worn or an additional screen placed in front of the CRT screen.
- LCM(liquid crystal modulator), works in active and passive modes.
    - Active: The LCM works the same as PLZT except it lets in twice as much light. New systems use an IR transmitter with a receiver in the glasses, instead of a wire connected to the glasses, providing a greater freedom of movement for the user.
    - Passive: The LCM, is mounted to the CRT screen. The LCM uses a circularly polarized cell that displays the left eye in one direction and the right in the other. Then the viewer has on the passive glasses that

are polarized to see the correct view. This also allows a greater degree of movement for the viewer, mostly due to the fact that there are no wires connected to the glasses.

- Mechanical, which works by alternating right and left views on the same CRT, must be at 120HZ so each eye gets 60HZ and it must be in sync with a shutter system to get right and left views at correct times. It was first used with a mechanical rotating cylinder with correct slits for left and right eyes.

The Time Parallel gives both left and right views at the same time, but the view has to be split. Ways to accomplish this are first; anaglyph that presents left and right eye views on a single CRT screen by the use of filters. The observer wears glasses that match the filter, an example being black and white presentations get a red and green-colored lens for the glasses, and for color presentations, red and cyan or green and magenta lens are used. The major problem that accompanies this display method is that it distorts the true colors of the image. The second way is, the separate image method that uses right and left displays for the right and left eye. The images are truly on different displays, i.e. HMD, dual screen, or split screen methods. Split screen often uses the partially-silvered mirror; this uses two displays at right angles to each other with filters. The user wears glasses that are polarized so each eye gets the correct view.

The different ways to generate a computer 3D display are off axis and on axis. Off axis takes the monoscopic view out to the distance of eye separation, and then rotates the field of view at the eyeball back towards the center of the Field Of View (FOV). Due to the rotation, the field of view is overlapping and is greater than the on axis method, thus this method is the preferred way to computer generate a 3D view. By moving the

monoscopic point of view again, the on-axis method is generated. The monoscopic eye point of view slides out horizontally from the center, again to the distance of the physical eye separation. This can be implemented in hardware, so it has better performance making it the most preferred method of computer image generation. To view an object, it has to be projected on the CRT by calculating the transformation required to map world coordinate vertices to view coordinate vertices.

Now that the objects to be projected and the eye position are in the same coordinate system, the objects can be projected onto the viewing plane. There are two main different types of projection: parallel, where there is no concept of distance from the viewer, and perspective, where the size of the projected image of the objects decreases as distance increases away from the viewer.

In the Parallel projection method, it is necessary to ignore the z coordinate. Any point x, y, z on the object to be projected produces a point (x, y) on the screen. Perspective projection is accomplished by scaling the x and y coordinates by a factor based on the z coordinate, which represents the distance from the viewpoint. (McAllister 1999; NCSU 1998)

Technology problems that occur because of interocular cross talk are, ghosting, CRT refresh rate and Image Scaling.

- Ghosting is a combined effect of phosphor persistence and shutter leak. This is when you see many different colors and many pictures of the same thing: this effect is most notable in old 3D movies. When a person goes to a 3D movie and puts the red and blue glasses on and can still see the red image in the blue lens and the blue image in the red.

- CRT refresh rate: If the refresh rate on a CRT is at 120 hertz, this provides 60 hertz to each eye for stereo vision. Then for the vertical resolution this refresh rate is divided again, so there are four sections; two for left eye stereo display and two for the right eye display. The end result is that each eye has a noticeable flicker at 30 hertz.
- Image scaling: There is an optimal viewpoint for an image viewed in stereo. Therefore, any movement away from the optimal viewpoint causes the image to elongate and distort.

C. EGOCENTRIC AND EXOCENTRIC DISTANCE PERCEPTION

The studies that have been completed in distance perception have mostly been involved with egocentric distances, from an observer to an object, such as Sinai, Krebs, Darken, Rowland, and McCarley's work (Sinai, Krebs, Darken, Rowland, and McCarley, 1999; Sinai, Ooi, and He 1998). Little work has been done in exocentric distances, judged distances between objects, or in motion parallax. Again, motion parallax is the additional information gained from moving the head to look at an object, or objects. From different views it might become clear that an object is rounder in the front than back correcting the perception that the object was closer than it was or actually is. The motion or lack of motion of the object under investigation provides more input to form that presence. Lampton proved that giving a verbal distance estimate in the real world and in virtual environments, observers can judge distances to be significantly shorter in the virtual environment than in the real world. (Lampton, Singer, and McDonald, 1995; Witmer and Kline, 1998) But, having the observer move an object to match distance seems to provide an accurate measurement in both the real and virtual worlds (Sinai, Krebs, Darken,

Rowland, and McCarley, 1999; Sinai, Ooi, and He 1998). This seems to be because an individual's perceived distance, of say a foot, will be different, and that difference will expand at farther distances. It has also been suggested by Roscoe that spatial information presented on any computer-generated display device will result in an apparent enlargement of distances (Roscoe, 1984). This is a key concept that the experiments in this thesis intend to prove incorrect. If this concept is correct, the question is, can the mind be trained to compensate for this apparent enlargement in judging distances in the real world?

D. TRAINING FEEDBACK

The training feedback for the experiments one through three, and five takes the form of metric and perceptual. Metric feedback is just giving a verbal report of the amount of distance the error was, as done in experiment number three. The question is how much is a foot to the participant being tested? And can they be trained to a real foot (12 inches) from their perception of a foot, by telling them the amount of their error? Lampton showed that when giving a verbal distance estimate in the real world and in virtual environments, observers judge distances to be significantly shorter in the virtual environment than in the real world (Lampton, Singer, and McDonald, 1995; Witmer and Kline, 1998).

Perceptual error is the participant seeing the amount of error, but giving no verbal metric amount, as done in experiment two. The question here is whether a picture is really worth a thousand words. Having the observer move an object to match distance seems to provide an accurate measurement in both the real and virtual worlds (Sinai, Krebs, Darken, Rowland, and McCarley, 1999; Sinai, Ooi, and He 1998). This seems to

be because an individual's perceived distance, of say a foot, will be different, and that difference will expand at further distances.

III. TRANSFER OF DISTANCE ESTIMATION SKILL

A. INTRODUCTION

This study exploited a well known transfer of distance-estimation skill—perceptual error—where people have a tendency to compress the distance along the in-depth plane between two objects in the frontoparallel plane. (Wagner, 1985; Loomis, Dasilva, Philbel, and Fuksima, 1996). Wagner showed that as the observed distance approached the perceived sagittal (depth) plane, there was an underestimation of the distance beyond which the distance was overestimated. Loomis used blind walking with binocular viewing and natural multicue environments to also confirm Wagner's work.

In this study, feedback was given to selected groups in the form of the amount of error using a distance measurement, a directional component, and zero error condition. Groups started in one environment, real or virtual, and then were tested in the other environment. The effect of this feedback should reduce the amount of error reported in the other tested environment.

B. SCOPE AND LIMITATIONS

The external validity of this experiment is expected to be very high since the results of this study could be applied anywhere in which training is required. Applications of training in the virtual environment, if proven successful, could greatly reduce training time and costs for the operational Navy. This experiment, however, was conducted on a limited basis since due to time constraints, only twenty participants were able to participate. Although each of the participants completed in eighteen different

trials, it would have been desirable to test them further at other time intervals, rather than just initially.

C. METHODS

1. Participants

The 20 participants tested were all male military officers, from foreign and U.S services, completing graduate level work in various curriculums. Their ages were between 25 and 36. All participants reported having normal or corrected to normal vision. All participants signed consent forms prior to testing.

2. Apparatus

The virtual environment was modeled using MultiGen and Vega by Mulligen-Paradigm Inc. and rendered on a Silicon Graphics Onyx Reality Engine. The frame rate was fixed at 30 frames/second. Head position was tracked with a Polhemus 3 Space Fastrack electromagnetic tracking system with six degrees of freedom. A V8 HMD manufactured by Virtual Research Systems was used to display the scene. The field of view was 60 degrees diagonal and the resolution was 600 x 480 pixels. Observers manipulated the distance of the comparison object using the joystick and a stop button on a BG System Flybox.

3. Procedure

The virtual room was 12 meters by 6 meters, the same as the room in the real world. The virtual room had a light green carpet, gray walls, and a blue ceiling (Figure 3). Differences in the real world were off white walls, white tile floor, and a white drop in

ceiling. The objects were centered 8 meters from the back wall, the same as in the real world. Two of the objects defined the spatial interval lying in a frontoparallel plane (the plane perpendicular to the line of sight that passes through the center of the spatial interval). The other two objects defined a spatial interval in depth (sagittal plane). Objects were brown in color and box-like in appearance, all measured the same size (.11m x .11m x .41m)(Figure 2). The observer was allowed to move the closest object to himself (object 4), which was always started at a point close to his observation point: .5 meters from the back wall.

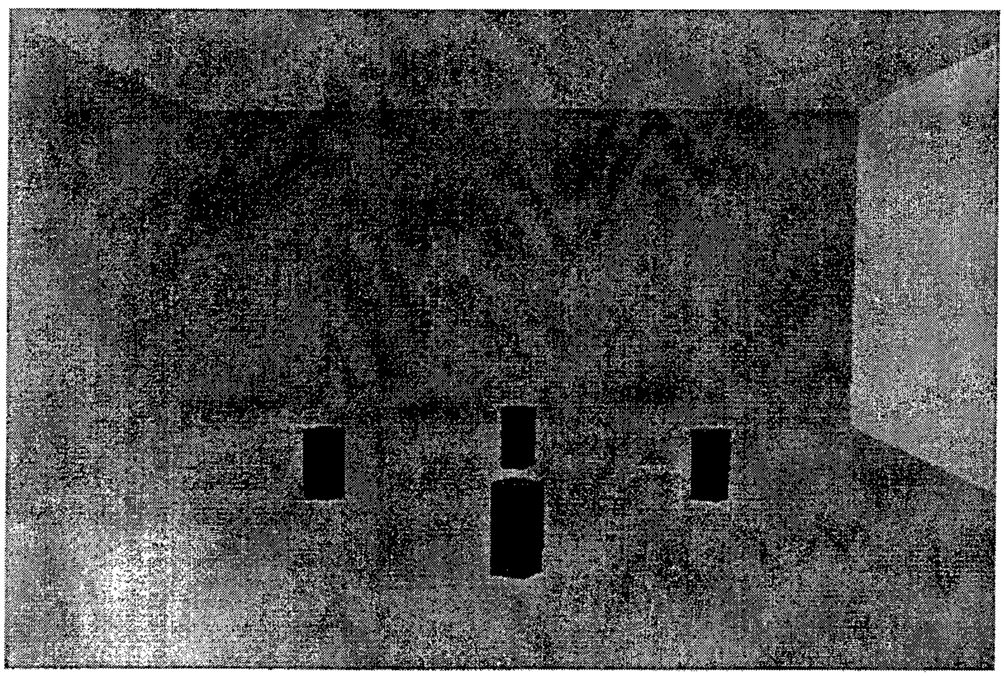

Figure 2. Virtual Environment as Shown in Distance Two

Participants were randomly assigned to one of four groups, with five participants per group. Group one was tested in the real world first then in the virtual environment with no feedback in either control group. Group two was tested in the real world with feedback and then tested in the virtual environment. Feedback consisted of telling the

participant how much error they had, in feet and inches, and then showing them the position of object 4 in the correct place. Group three was tested in the virtual environment then in the real world (control group 2). Group four was tested in the virtual environment with feedback, and then tested in the real world. All observers had a total of eighteen tests; nine real world and nine virtual environments. All tests were conducted in a random order for both environments.

The nine tests consisted of three sets of distances. In distance one, the objects one, two, and three were .91 meters (3 feet) from the center point. In distance two, the objects were set up 1.22 meters (4 feet) from the center. In distance three, the objects were 1.52 meters (5 feet) from the center (Figure 3). Each participant was told to match the distance of object one and three (frontoparallel plane) to objects two and four (sagatti plane) by moving object four.

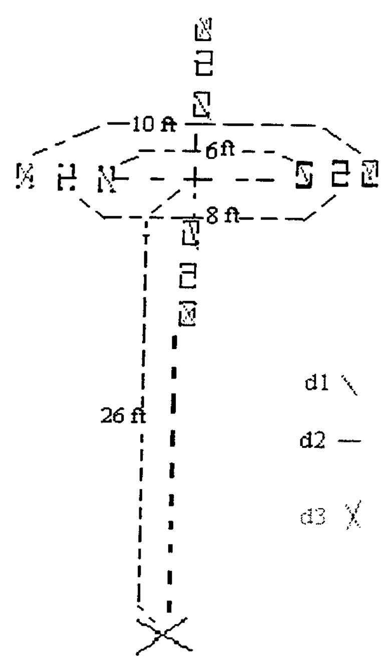

Figure 3. Setup Experiment One

D. RESULTS

After all participants completed the tests, the data was converted into inches. For each group, the average and standard deviation were calculated and plotted (Table 1) and then graphed (Figure 5). For the training transfer graph (Figure 6), the training transfer was computed by using the real world error with no feedback divided by two (for the two non feedback groups) minus the real world error after the virtual environment training was completed. The same calculation was used for computing the virtual world training transfer.

	Rw- Vw	Feed	Vw- Rw	Feed
Avg Rw	19.70	4.02	16.93	8.50
Std-dev	9.50	7.50	9.50	9.16
Avg Vw	43.90	23.00	25.76	9.09
Std-dev	18.00	11.70	13.10	17.50
	15.68		8.43	

Table 1. Experiment One Results

E. DISCUSSION

From Figure four it is clear that training given in both the real world and the virtual environment improved performance in tests conducted in the other world. Of special note is training given in the virtual environment dramatically decreased the error in the real world tests, compared to the control condition in which no feedback was given. There was more error in the virtual environment compared to the real world (Lampton, Singer, and McDonald, 1995; Witmer and Kline, 1998).

The t-test had P(T <=t) two tail of 0.196. This test compares the five average changes in group three to the five in group four. The model says each individual has about the same variability, the different distances have about the same effect, and the effect of training is additive. The "null hypothesis" is the "effect of training is 0." Since the result has a p-value of .2. The null hypothesis cannot be rejected since there is no evidence. The t-test is based on the variances being equal. However, because of the small population size, and the amount of noise in the experiment. 16 participants had bigger standard deviations in the virtual world so variances were larger in the virtual (18.7) than in the real (11.13). The t-test does not prove much here. For further analysis of variance see chapter four discussions. As distance increased so did the amount of the average error, 14.134, 18.441, and 23.61.

The hypothesis was that there should be the same amount of training transfer in both worlds. The results concluded that there is a greater amount of training transfer from the virtual environment to the real world than real world to virtual environment (Figure 4).

The test hypothesis was to see if there was a training transfer effect that would allow training to be conducted in a virtual environment rather than in the real world. In this test, there is strong evidence that the ability to judge distance accurately in the virtual environment increased judgments in the real world. After debriefing the participants it was concluded that when the observers used the three fixed objects to judge the perceptual error of an object, then the participants use the furthest fixed object in the distance along the in-depth plane, with two fixed objects in the parallel plane to judge whether there was something wrong in the distance perception of the objects. This was

the correct judgment given for the condition. This wrong perception is the compression that was being used in the study. The participants used this to try to compensate for their estimations. From Figure 4 it is clear that training given in both the real world and the virtual world improved performance in tests conducted in the other world. Of special note is training given in the virtual world dramatically decreased the error in the real world tests. Test results suggest that there is more error in the virtual world than in the real world. (Lampton, Singer, and McDonald, 1995; Witmer and Kline, 1998). From Figure 5 it is clear that a training transfer exists as shown. The emphasis here is that there is a greater transfer of training when a participant is trained in a virtual world first.

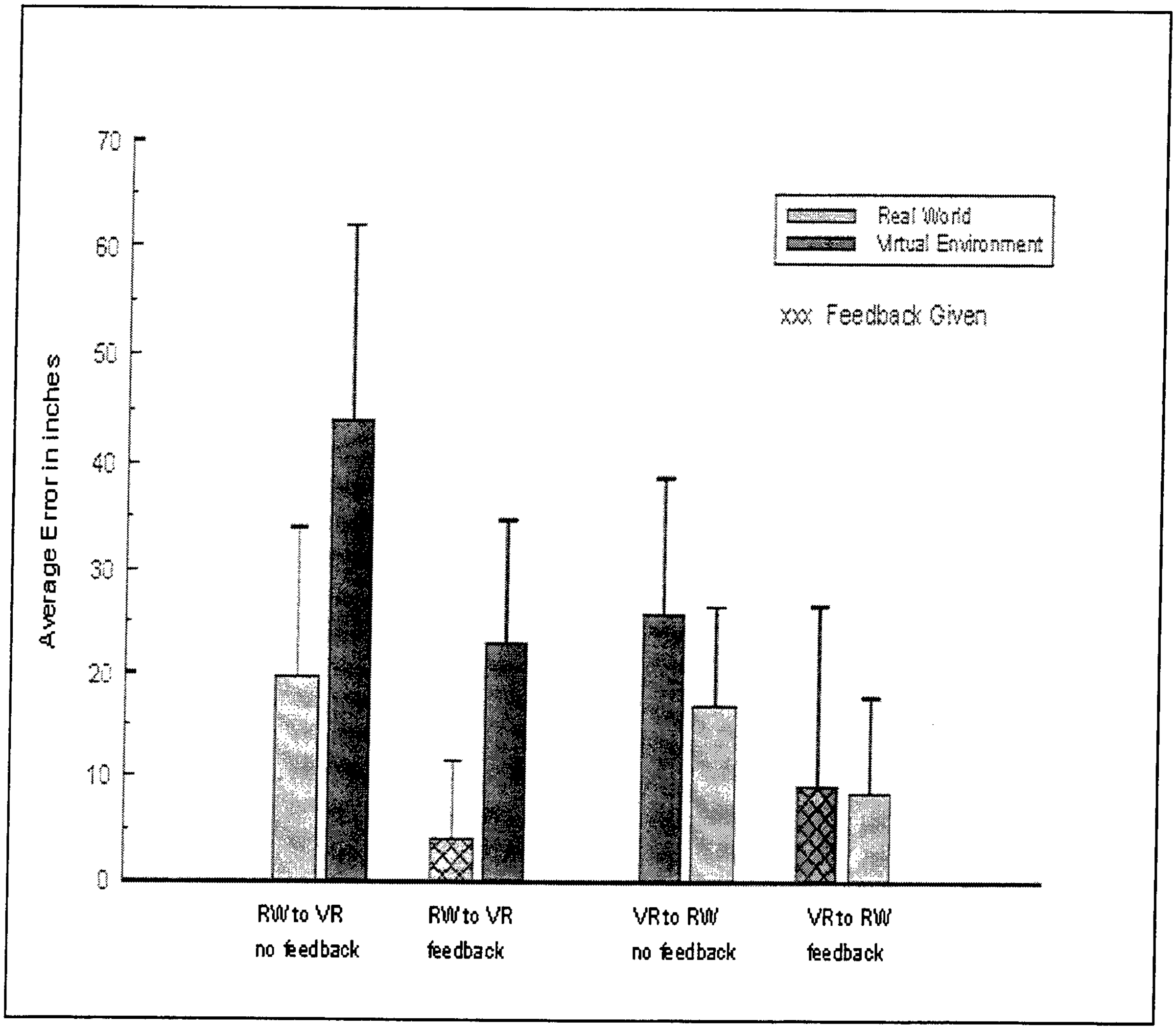

Figure 4. Average Error Versus Groups

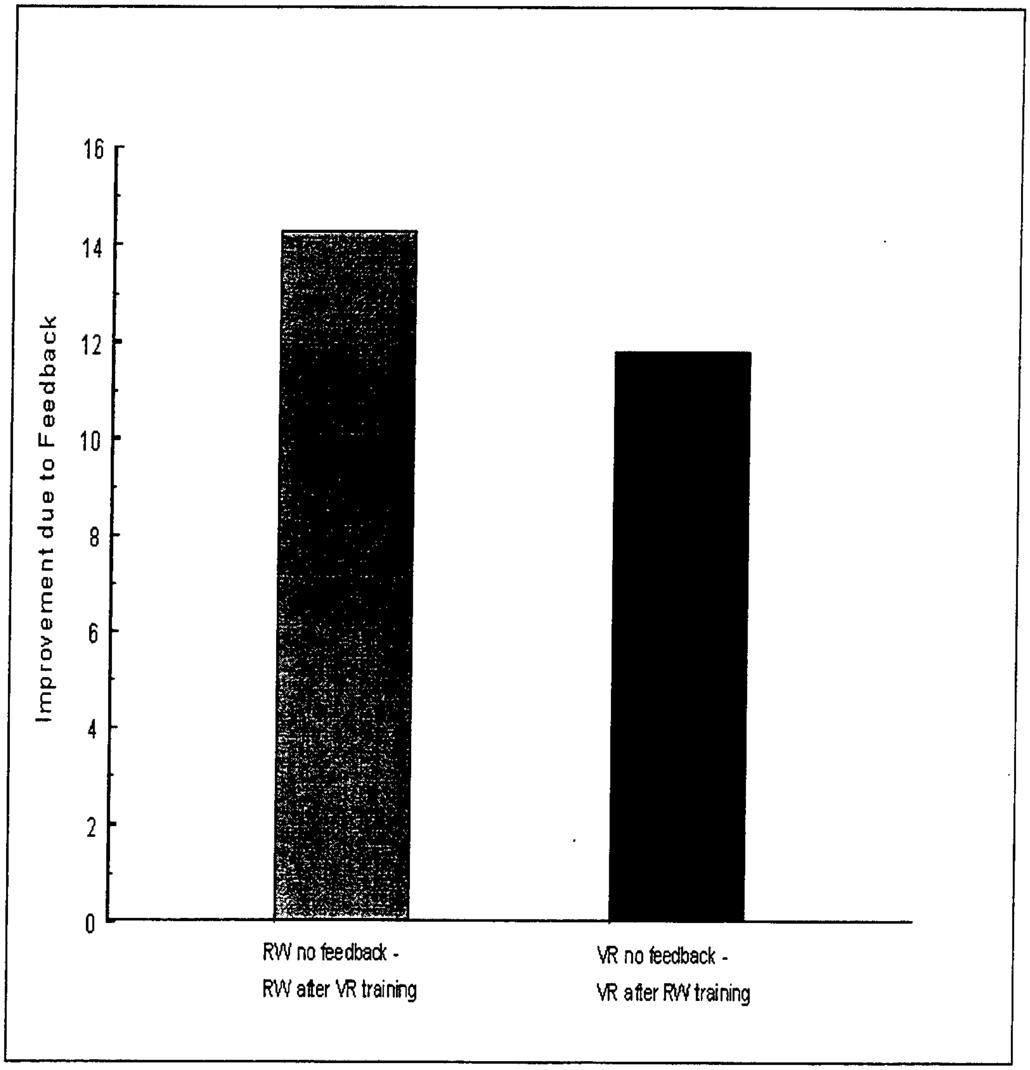

Figure 5. Training Transfer Versus Worlds

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IV. PERSPECTIVE FEEDBACK

A. INTRODUCTION

Training a person / soldier is a very expensive and time-consuming task. To reduce the cost and to save time, experts are trying to find ways to solve the problem of training. One of the possible solutions is to use a virtual environment. In this project the same procedure was followed as in the previous experiment. To do this, a test was implemented to judge egocentric distance perception and to see if a perceived distance in the virtual world mapped one to one to the perceived distance in the real world. Training feedback was given in the form of allowing the participant to see the amount and direction of error from the actual position. The participants were not told the amount of error or the actual distance of the object. In this test, the object was at a fixed distance from the participant in both the real and virtual environment. After each condition, the training feedback was given. Observations were then taken on whether or not the participant could transform what they saw in the virtual environment to the real world, and vice versa. Here the goal was to get the same result in both environments and to see whether the participants' depth perception ability could be improved in the virtual and real world, so that the military can save time and money. Is there also a retention difference? Waller and Miller showed a long term transfer with a one week duration. (Waller and Miller 1998) This test used a two week duration.

B. SCOPE AND LIMITATIONS

The external validity of this experiment is expected to be very high since the results of this study could be applied anywhere in which training is required.

Applications of training in the virtual environment, if proven successful, could greatly reduce training time and costs for the operational Navy. This experiment, however, was conducted on a limited basis due to time constraints. Only four participants were able to participate. Although each of the four participants completed in five total hours of experimentation, it would have been desirable to test them further at other time intervals, rather than just initially and two week later.

C. METHODS

1. Participants

The four participants tested were all male military officers from the Turkish Army and Navy. Ages were between 20 and 27. They are completing graduate level work in operations analysis at the Naval Postgraduate School. All participants had normal or corrected vision and signed consent forms before the experiment.

2. Apparatus

The virtual environment was modeled using MultiGen and Vega by Mulligen-Paradigm Inc. and rendered on a Silicon Graphics Onyx Reality Engine. The frame rate was fixed at 30 frames/second. Head position was tracked with a Polhemus 3 Space Fastrack electromagnetic tracking system with six degrees of freedom. A V8 HMD manufactured by Virtual Research Systems was used to display the scene. The field of view was 60 degrees diagonal and the resolution was 600 x 480 pixels. Observers manipulated the distance of the comparison object using the joystick and a stop button on a BG System Flybox.

3. Procedure

The virtual test and the real world test were run in the same room. For the real world, the participant rotated 90 degrees, lifted the HMD, and gave verbal cues to a lab assistant to move an object. The real world room was approximately the same size as the virtual world (12 by 6 meters). The virtual room had a green floor, gray walls, and a blue ceiling with the object being a brown box (.11meters by .11 meters by .41 meters). In the real world the walls were white, there was a white drop in ceiling, and the floor was brown. In the distance perception test feedback was provided to the participants as a demonstrated amount, no verbal amounts, indicating how much error they had and the real position of the object both in virtual and real world depending on what environment they were being tested in. We tested the same people four days in a row with feedback. At the end of two weeks the same participants were tested once to see the amount of training retained. In the twenty-four tests, it took about one-hour to run each participant; there were 12 virtual environments and 12 real world environments. Tests were conducted in a random order for both environments.

The experiment consisted of two phases. In the first phase the position of the object was shown in the real world and participants were asked to move the object in the virtual environment to match distances. Then the participants were given feedback and shown the real position of the object. In the second phase the position of the object was shown in the virtual environment and participants were asked to move an object in the real world in order to match what they saw in the virtual world (Figure 6). Feedback was given at the end of every condition.

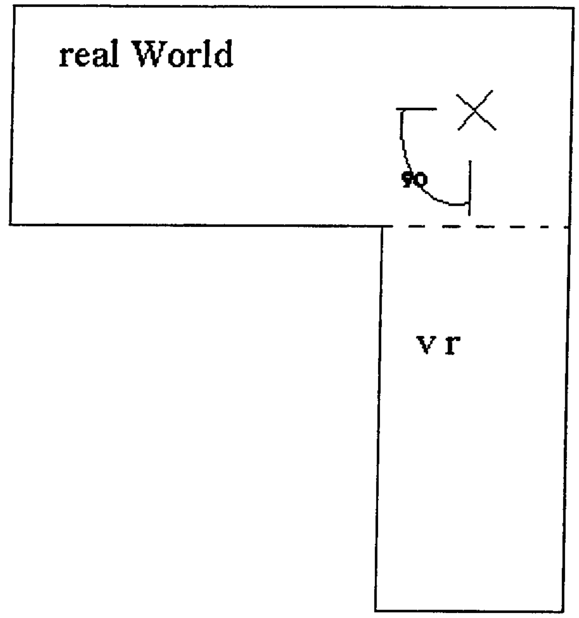

Figure 6. Setup for Experiment Two

D. RESULTS

The error term that was used is the difference between the estimated distance and the true distance. Error = Estimated distance - True distance. If the error is negative, observers underestimated the distance. If it is positive, they overestimated the distance. When the data is examined the absolute values of the errors are used. After all participants completed the tests, the data was converted into inches. For each trial the average and standard deviation were calculated (Table 2) and plotted (Figure 7).

		Real	Vr	Mean
Trial 1	Avg	1.579	2.784	2.1815
	Std Dev	1.556	2.304	1.9300
Trial 2	Avg	0.775	1.040	0.9075
	Std Dev	0.686	0.899	0.7925
Trial 3	Avg	0.712	1.082	0.8970
	Std Dev	0.467	0.973	0.7200
Trial 4	Avg	0.691	0.954	0.8225
	Std Dev	0.438	0.954	0.6960
Trial 5	Avg	0.340	0.884	0.6120
(2 weeks)	Std Dev	0.203	0.570	0.3865

Table 2. Experiment Two Results

E. DISCUSSION

Continuous improvements were expected in each trail. This was the case in the real world for trials one through four and approximately true for the virtual world. However from Figure 5, it is clear that after the rest period, the participants came back and did better in both the real world and the virtual world (Trial 5). Improved performance in trial five suggests that participants were saturated from the four days of continuous training. There was more error in the virtual environment compared to the real world (Lampton, Singer, and McDonald, 1995; Witmer and Kline, 1998).

The theory was that there should be a greater amount of error in the final test (Trial 5), compared to the completion of the training cycle (Trial 4). The results conclude that the participant did better in trial five (Figure 8).

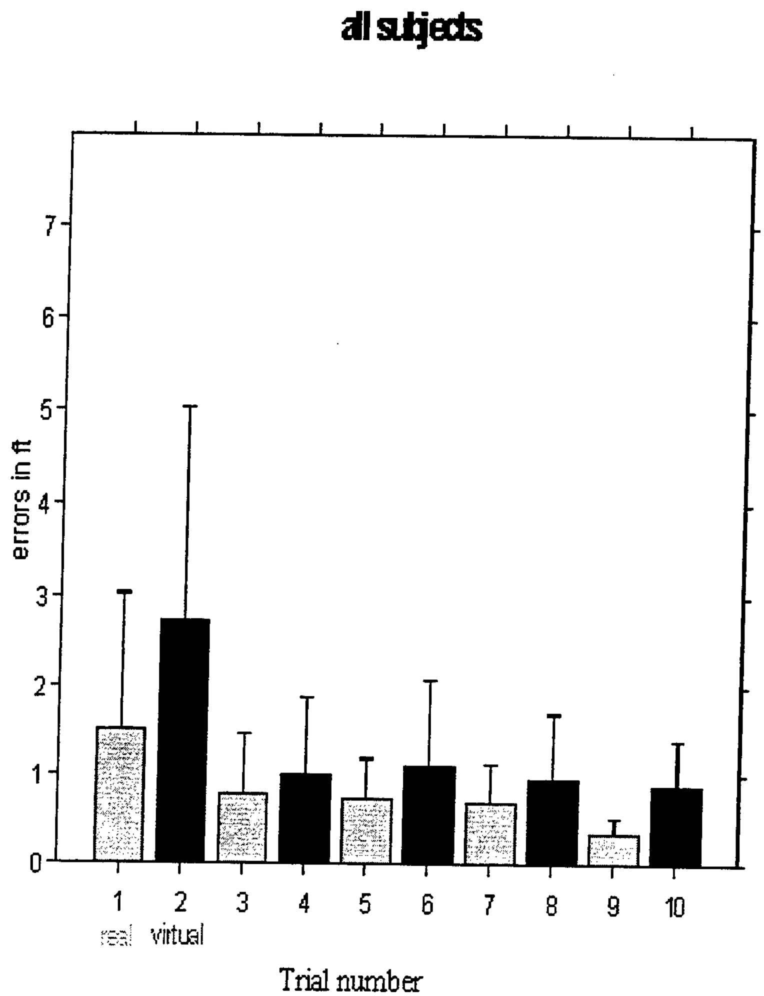

Figure 7. Error Versus Trial Number

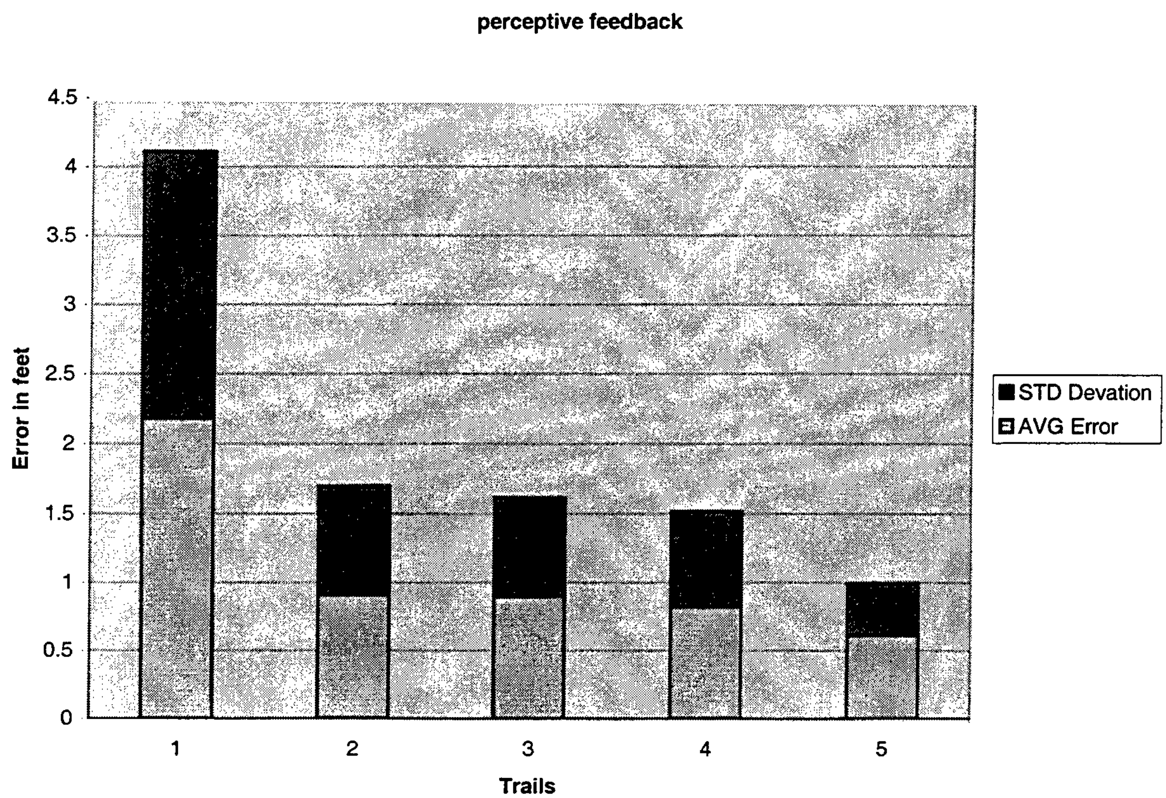

Figure 8. Error Versus Trials

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V. METRIC FEEDBACK

A. INTRODUCTION

This experiment was designed to quantify the effect of a virtual environment training intervention applied to real world environment performance. Previously, numerous studies have found that observers significantly underestimate egocentric distance judgments while immersed in a virtual environment (Witmer and Kline, 1998; Henry and Furness, 1997; James, and Caird, 1995; Lampton et al., 1995). These studies found distance estimations were significantly shorter in the virtual world compared to the real world for a verbal reporting magnitude estimation task (Witmer and Kline, 1998). The hypotheses in this study will investigate if there is an improved "training effect" from the virtual environment to a real world environment, by applying a metric feedback to real and virtual world distances. Participants were shown distances in the real or virtual world and then asked to apply their "trained eye" to approximate the distance in the other environment.

There is significant U. S. Navy interest in virtual environment training in order to reduce training costs. The benefits of such training applied to real world situations are often difficult to quantify. It is critical to the success of the Navy that its training is effective, but there is substantial risk inherent in training in a non-real world environment. One problem with training in a virtual environment is the poor transfer of spatial information from the virtual environment to the real world (Witmer, Bailey, Knerr, and Parsons, 1996; Bliss, Tidwell and Guest, 1997; Waller, Hunt and Knapp, 1998; Darken and Banker, 1998). One possible contributing cause of this training

transfer problem may be due to poor distance perception that typically accompanies immersion in a virtual environment.

There were two expected results in this study. The first hypothesis is that the participants exposed to feedback over four training sessions in one week will improve accuracy of distance estimation. The second hypothesis is that their improved accuracy would be retained for the second training session in that there would be a lesser learning curve upon initiation of the second set of four training sessions. The experiment was set up as a within participant test, which improved its robustness.

B. SCOPE AND LIMITATIONS

The external validity of this experiment is expected to be very high since the results of this study could be applied anywhere in which training is required. Applications of training in the virtual environment, if proven successful, could greatly reduce training time and costs for the operational Navy. This experiment, however, was conducted on a limited basis since, due to time constraints, only four participants were able to participate. Although each of the four participants completed in eight total hours of experimentation, it would have been desirable to test them further at other time intervals, rather than just initially and two week later.

C. METHODS

1. Participants

The four voluntary participants tested were three male military officers from the U. S. Navy, completing graduate level work in various curricula, and one female teacher/military officer's wife. All individuals' ages were between twenty-seven and thirty-three. All participants reported having normal or corrected to normal vision. All participants signed consent forms prior to testing.

2. Apparatus

The virtual environment was modeled using MultiGen and Vega by MultiGen-Paradigm Inc. and rendered on a Silicon Graphics Onyx Reality Engine. The frame rate was fixed at 30 frames/second. Head positions were tracked with a Polhemus 3 Space Fastrack electromagnetic tracking system with six degrees of freedom. A V8 HMD manufactured by Virtual Research Systems was used to display the scene. The field of view was 60 degrees diagonal and the resolution was 600 x 480 pixels. Observers manipulated the distance of the comparison object using the joystick and a stop button on a BG Systems Flybox.

3. Procedure

The virtual room was 40 feet by 20 feet, the same as the room in the real world. The virtual room had a light green carpet with gray walls, and a blue ceiling. The real world colors were off white walls, white tile floors, and a white drop-in ceiling. The object defined was the spatial interval lying in a frontal parallel plane (the plane perpendicular to the line of sight that passes through the center of the spatial interval).

The object was brown in color and rectangular box-like in appearance; the object in the virtual world and real world measured the same size (.11m x .11m x .41m). The observer was allowed to move the object toward or away from the participant. The observer always started at a point close to the participant, which was 10 feet from the participant (Figure 9). The data collection program randomly assigned participants to perform one of two different tasks. The first was to view the object at a certain distance in the real world and place it at the equivalent distance away from the participant with the Flybox into the virtual world. The second task was to view the object at a certain distance in the virtual world and place it in the real world. Feedback consisted of telling the participant how much error they had, in feet and inches. All participants completed eight tests, each consisting of twenty-four random tasks. Each participant was required to wait two weeks before the second four tests were completed. All tests were conducted in a random order for both environments. The tasks consisted of four different distances: twenty, twenty-five, thirty, or thirty-five feet.

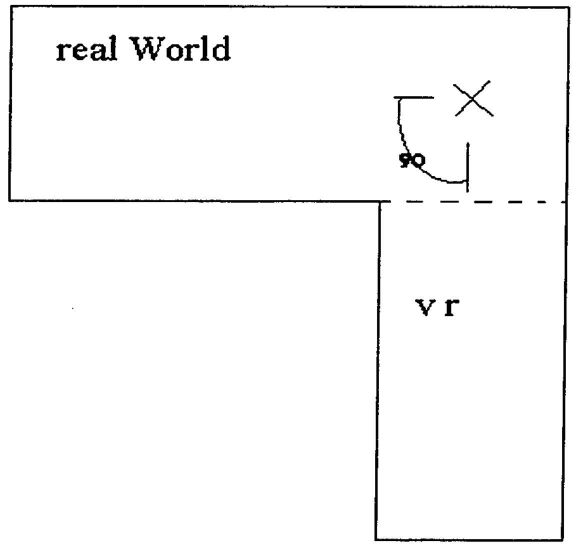

Figure 9. Setup for Experiment Three

D. RESULTS

Participants were shown distances in the real or virtual world, then asked to approximate the distance in the other environment. The absolute value of the error in estimation was collected (Table 3); therefore all tests conducted were non-signed tests. After this the averages and standard deviations were calculated.

Trials	1	2	3	4	5	6	7	8
Avg	2.258125	1.132708	0.80625	0.898854	1.107708	0.593125	0.356563	0.374271
Std Dev	2.242853	0.921171	0.65626	0.808584	0.883937	0.487257	0.295235	0.378248

Table 3. Experiment Three Results

E. DISCUSSION

The first hypothesis is that the participants will improve over the four training sessions in both time periods.

Since each participant was required to wait two weeks before the second four tests were completed, it was desirable to determine if there was a "training retention effect." The second hypothesis is that their training in the first four sessions will carry over two weeks later; although there will be another learning curve upon initiation of the second set of four training sessions, this second learning curve will not be as steep.

To test the two hypotheses, an ordinary least squares linear regression and an Analysis of Variance, ANOVA, were conducted. A main effects additive model was utilized. The ANOVA model consisted of the absolute value of the participant's error as the response variable. There were three predictor variables in the analysis: participant, time period (either week one or week two), and hour of experiment within each time period. Unfortunately, the regression model exhibited large heteroscadasticity, and unequal variances. ANOVA regression is always an unbiased estimator, yet the unequal variances exhibited in the residual vs. fit plot make this a non-optimal model.

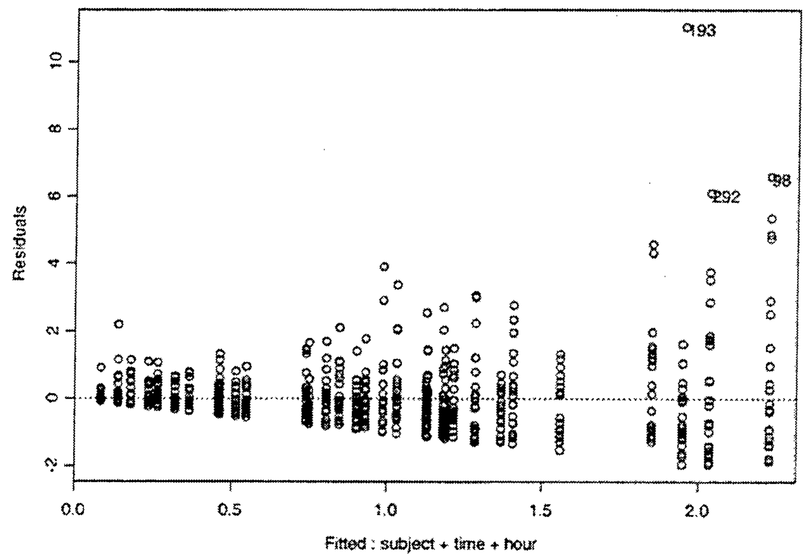

Figure 10. Residual Versus Fit Plot

Figure eleven illustrates the problem of heteroscadasticity in the ordinary least squares regression. Attempted transformations of the response variable to remove the unequal variances were unsuccessful. Since ANOVA regression is always an unbiased estimator and is robust to non-normality, results of the current regression were analyzed. The P-value for the F statistic from the ANOVA table for hour in each time period was less than 1.0×10^{-8}. This value is so unlikely, even in a non-optimal regression, that this difference over hours within time periods are unlikely to be caused by chance. The P-value for the F statistic from the ANOVA table the period of time the study was conducted was also less than 1.0×10^{-8}. This value is so unlikely, even in a non-optimal regression that this difference over time periods is unlikely to be caused by chance.

To confirm the results graphically, interaction plots between the predictor variables were generated. (Figure 11)

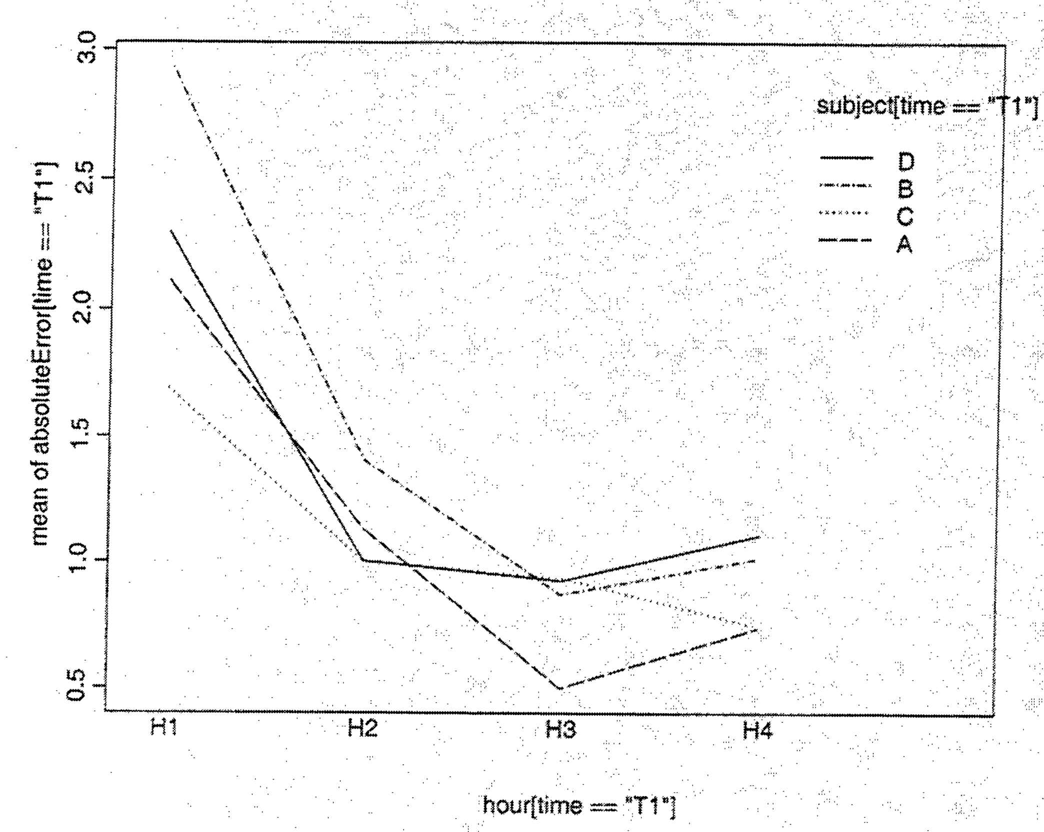

Figure 11. Interaction Plot of Predictor Variables Time One

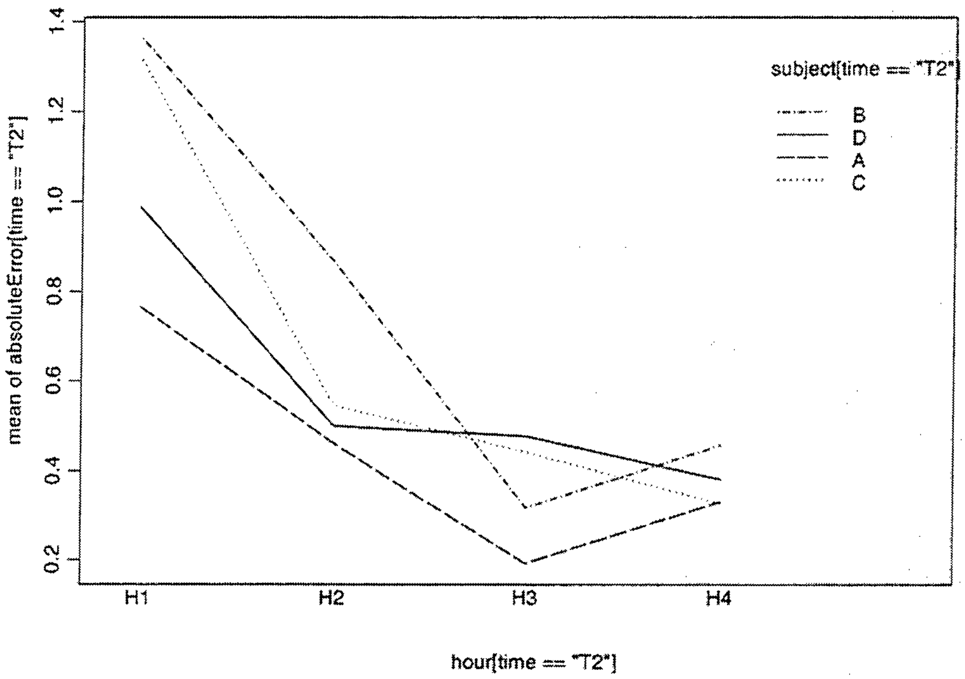

Figure 12. Interaction Plot of Predictor Variables Time Two

Each line on Figures eleven and twelve is for a different participant. The x-axis in Figure eleven indicates the hour the study was conducted in time period one. The x-axis in Figure twelve indicates the hour the study was conducted in time period two. The y-axes in both Figures indicate the average of the absolute value of the errors for each participant.

Both figures eleven and twelve show a significant downward slope in the absolute value of each participant's error over hours. Even though this slope levels off between the third and fourth hour, this graphically confirms the results of the ANOVA. The first hypothesis was that there is a learning curve each time participants are exposed to the

virtual environment. Therefore, the participants would improve over the four training sessions in both time periods.

The scale on the y-axes of Figure eleven and twelve indicate the average of the absolute value of the errors for each participant. In Figure twelve, the values on the y-axis of the graph are lower than in Figure eleven. This graphically confirms the results of the ANOVA a period of time as a predictor variable. The second hypothesis indicates that retention of what was learned in the first period is evident in the comparison of the interaction plots. Shown by the ANOVA and the interaction plots, participants performed much better in the first hour of the second time period than they did during the first period.

The ANOVA test results confirmed both of the initial hypotheses. Both time periods and hours within time periods proved to be significant in the regression. Graphically, the interaction plots illustrated the ANOVA results. Figures eleven, twelve, and thirteen demonstrate that there is a significant learning curve associated with the transfer of training involved in the virtual environment as illustrated by the downward slopes on both of the interaction plots. The hypothesis that each participant will improve over hours in each time period is confirmed by the p-value of the F-test. However, performance from hour 3 to hour 4 within each time frame does not follow the trend (Figure 13). Each participant experienced an increase in the absolute errors between these periods, which seems contrary to the hypothesis that failed to rejected. This increase in errors is minor, and is attributed to each of the participant's plateau in the application of the training or their desire to complete the experiment. The study could have been

improved with more participants and less repetition for each participant. This would have provided more data to support the hypothesis.

The y-axis on the interaction plots illustrates why the F statistic in the ANOVA table led to the failure of rejecting the second hypothesis of retention of what was learned from the first period to the second period. Participants performed much better in the first hour of the second time period than they did during the first period. Participants appeared much more comfortable with the virtual environment apparatus and equipment over time, which probably also contributed to the success of participants at the beginning of the second period. Having more than four participants to validate this hypothesis would have been beneficial, however since all four of the participants improved so significantly at the beginning of time two, the failure to reject the hypothesis is acceptable based on the data collected and the regression results.

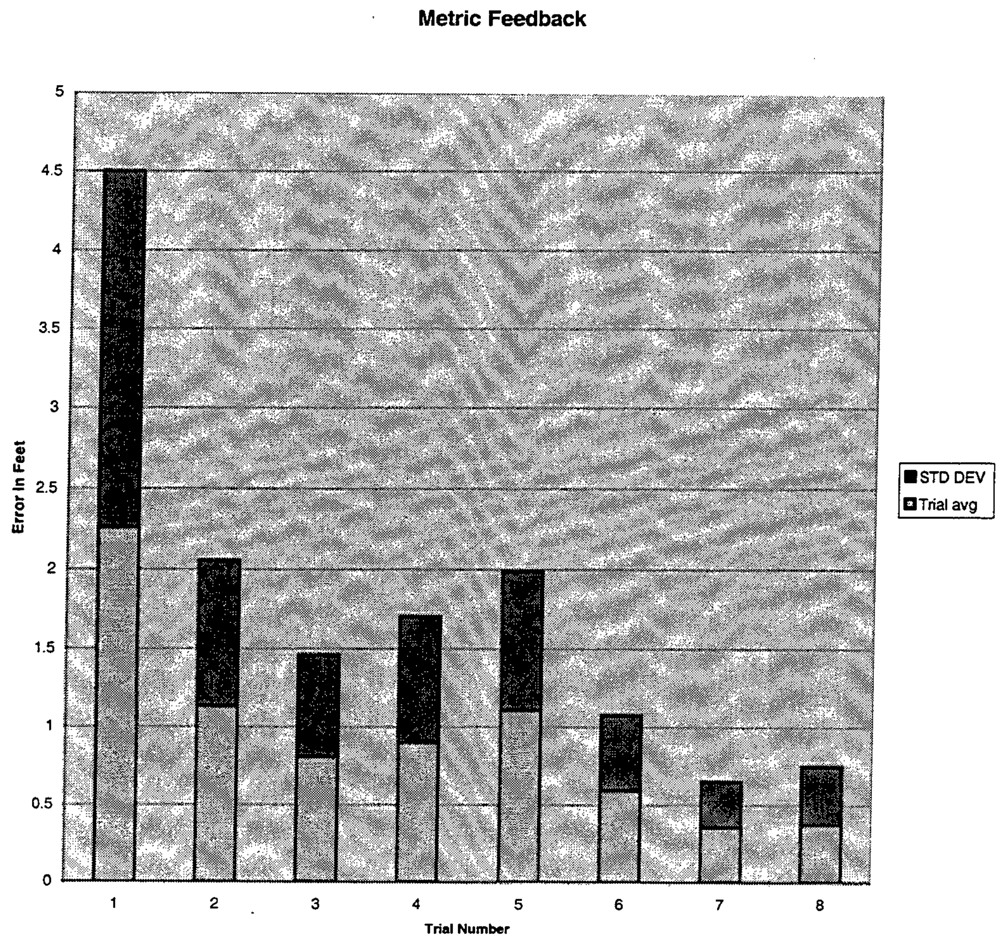

Figure 13. Average Error Versus Trial Number

VI. GEOMETRIC FIELD OF VIEW

A. INTRODUCTION

Lampton showed that when giving a verbal distance estimate in either the real world or in a virtual environment the estimate tends to be significantly shorter in the virtual environment than in the real world. (Lampton, Singer, and McDonald, 1995; Witmer and Kline, 1998) Having the observer move an object to match a given distance seems to provide a more accurate measurement in both the real and virtual worlds (Sinai, Krebs, Darken, Rowland, and McCarley, 1999; Sinai, Ooi, and He 1998). This seems to be because an individual's perceived distance, of say a foot, will be different from person to person and that difference will expand at further distances.

This study used a well know perceptual error where distance estimates between two objects appears to be compressed along the in-depth plane, relative to an equal distance in the frontoparallel plane. (Wagner, 1985; Loomis, Dasilva, Philbel, and Fuksima, 1996). The Geometric Field of View (GFOV) was set up to be 30 degrees, 60 degrees, and 90 degrees. The independent variables for this experiment are GFOV and the three treatment conditions. The effect of this FOV should be a reduction in the amount of error reported in the 60-degree setup, because the HMD has a 60 degree Physical Field Of View (PFOV).

Human performance in a head-mounted display depends largely on the display's FOV. Light enters the eyes through an angular visual field that spans approximately 200 degrees horizontally and 150 degrees vertically, but this is not matched by typical Head-Mounted Displays (HMD's), nor is it known whether this needs to be for all tasks. Many commercially available HMD's have relatively narrow PFOV's, ranging from roughly 30

to 70 degrees diagonally. Narrow PFOV has been shown to degrade human performance on navigation, spatial awareness, manipulation, and target-tracking tasks, and to disrupt the eye head-movement coordination and the perception of size, space, and ego-center. Wide FOV displays are not yet generally available; nerveless, even after the engineering difficulties of realizing them are overcome, choosing the widest FOV possible may not be optimal for many applications. A wide FOV will aggravate simulator sickness effects, and, in particular, those due to vection and visual-vestibular mismatch. In addition, this may just not be necessary for a task that is localized in a small region of space. (Alfano, George, 1990)

B. SCOPE AND LIMITATIONS

The external validity of this experiment is expected to be very high since the results of this study could be applied anywhere in which training is required. Applications of training in the virtual environment, if proven successful, could greatly reduce training time and costs for the operational Navy. This experiment, however, was conducted on a limited basis since, due to time constraints, only five participants were able to participate.

C. METHODS

1. Participants

The five participants tested were all male military officers, from U.S services, completing graduate level work in various curricula. Their ages were from 25 to 36 years. All participants reported having normal or corrected to normal vision. All participants signed consent forms prior to testing.

2. Apparatus

The virtual environment was modeled using MultiGen and Vega by MultiGen-Paradigm Inc. and rendered on a Silicon Graphics Onyx Reality Engine. The frame rate was fixed at 30 frames/second. Head position was tracked with a Polhemus 3 Space Fastrack electromagnetic tracking system with six degrees of freedom. A V8 HMD manufactured by Virtual Research Systems was used to display the scene. The field of view was 60 degrees diagonal and the resolution was 600 x 480 pixels. Observers manipulated the distance of the comparison object using the joystick and a stop button on a BG System flybox.

3. Procedure

The virtual room was 12 meters by 6 meters with a light green carpet and gray walls, and a blue ceiling. The objects were centered 8 meters from the back wall. Two of the objects defined the spatial interval lying in a frontoparallel plane (the plane perpendicular to the line of sight that passes through the center of the spatial interval). The other two objects defined a spatial interval in depth (sagatti plane). The objects were brown in color and box like in appearance, all measuring the same size (.11m x .11m x .41m)(Figure 2). All observers had a total of twenty-seven tests conducted in a random order. In distance one, objects one, two, and three were .91 meters (3 feet) from the center point. In distance two, the objects were set up 1.22 meters (4 feet) from center, and in distance three the object were 1.52 meters (5 feet) (Figure 14). The participant was told to match the distance of object one and three (frontoparallel plane) to objects two and four (sagatti plane) by moving object four. In all treatment conditions, the PFOV was constant, set to 60 degrees. There were three experiential GFOV's: 30, 60,and 90 degrees.

For each GFOV, participant's viewed three scenes, where the distance between objects varied. Thus, there were nine treatment conditions. Participants were exposed to each of the nine treatment conditions three times each, for a total of twenty-seven trials.

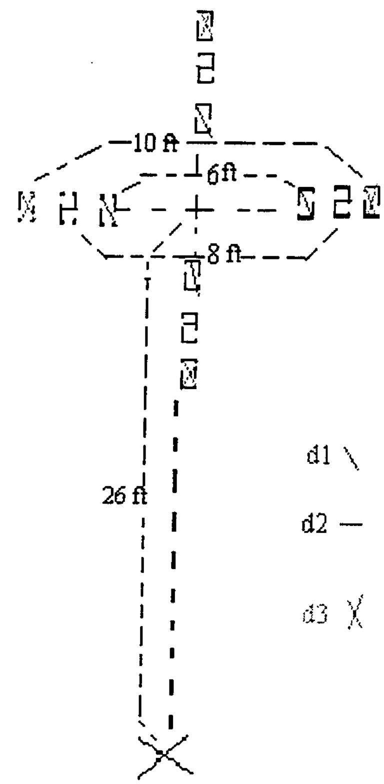

Figure 14. Setup for Experiment Four

D. RESULTS

After all participants completed the tests, the data was converted from percentages of a foot to inches (Table 4). For each group the average and standard deviation were calculated and plotted (Figure 14).

GFOV	Distance	Mean	Std Deviation
30	D1	17.128	4.502721
30	D2	21.816	2.673854
30	D3	32.67933	3.621154
60	D1	18.416	5.342434
60	D2	24.76	2.673854
60	D3	24.584	6.195039
90	D1	21.616	4.502721
90	D2	20.19467	5.551339
90	D3	25.856	3.621154

Table 4. Experiment Four Results

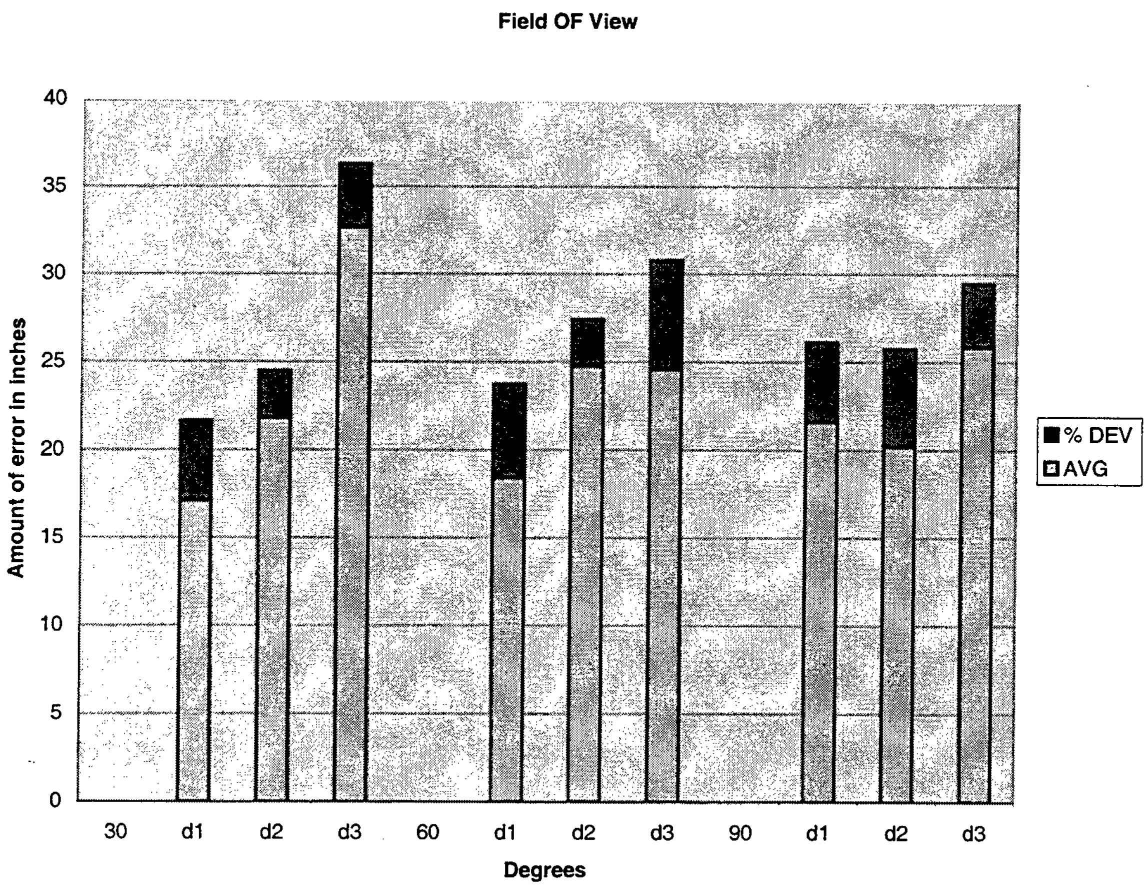

Figure 15. Field Of View Versus Error

E. DISCUSSION

Given that the slope from the 30-degree condition and the 60-degree condition are almost the same, Figure sixteen renders the conclusion that the optimal field of view will be between these two settings. The results were sent to the HMD manufacturer where their conclusions with the data suggest that a 48-degree Field of view will be the optimal setting for the Horizontal Field of view setting. Regressions suggest no interaction between factors (Table 5).

	DOF	Sum of Squares	Mean Square	F Value	Pr(F)
Fv	1	39.14	39.138	0.37386	0.5422306
Dist	2	1722.55	861.276	8.22715	0.0004795
Subj	4	11673.33	2918.332	27.87674	0.0000000
fv:dist	2	480.83	240.414	2.29650	0.1056429
fv:subj	4	127.96	31.989	0.30557	0.8736781
dist:subj	8	961.64	120.205	1.14823	0.3377641
fv:dist:subj	8	502.85	62.856	0.60042	0.7756494
Residuals	105	10992.14	104.687		

Table 5. Regression Results

VII. THE COGNITIVE RELATIONSHIP

A. INTRODUCTION

Training programs have become very time consuming and expensive in the real world, especially in the case of combat training, which is often impossible to simulate. Can conducting a portion of this training in a virtual environment save time and money? This study investigates if the cognitive prescreening can predict distance estimation performance level. The task is distance perception and the prescreening condition being used is a cognitive task used to judge organizational capabilities of the test participants. Participants were trained for the task using a training transfer task. It is already known that if giving a verbal distance estimate is given in the real world and in virtual environments, the observers judge distances to be significantly shorter in the virtual environment than in the real world. (Lampton, Singer, and McDonald, 1995; Witmer and Kline, 1998) But, having the observer move an object to match distance provides a more accurate measurement in both the real and virtual worlds (Sinai, Krebs, Darken, Rowland, and McCarley, 1999; Sinai, Ooi, and He 1998).

This study used a well know perceptual error where distance estimates between two objects appears to be compressed along the in-depth plane, relative to an equal distance in the frontoparallel plane. (Wagner, 1985; Loomis, Dasilva, Philbel, and Fuksima, 1996).

B. SCOPE AND LIMITATIONS

The external validity of this experiment is expected to be very high since the results of this study could be applied anywhere in which training is required. It is not the author's intent to type and classify persons or personal behavior. Applications of training in the virtual environment, if proven successful, could greatly reduce training time and costs for the operational Navy. This experiment, however, is conducted on a limited basis since, due to time constraints, only eighteen participants were able to participate.

C. METHODS

1. Participants

The 18 participants tested were all military officers, from U.S services, completing graduate level work in various curricula. Their ages were between 25 and 36. All participants reported having normal or corrected to normal vision. All participants signed consent forms prior to testing. Equipment failure caused the loss of the data for participant eight.

2. Apparatus

The virtual environment was modeled using MultiGen and Vega by MultiGen-Paradigm Inc. and rendered on a Silicon Graphics Onyx Reality Engine. The frame rate was fixed at 30 frames/second. Head position was tracked with a Polhemus 3 Space Fastrack electromagnetic tracking system with six degrees of freedom. A V8 HMD manufactured by Virtual Research Systems was used to display the scene. The field of view was 60 degrees diagonal and the resolution was 600 x 480 pixels. Observers manipulated the distance of the comparison object using the joystick and a stop button on

a BG System flybox. The real world environments were conducted outside in a grassy area near the lab building, using four boxes with the same dimensions as the test objects from the virtual world. The cognitive test was conducted on a concrete patio area outside the lab building using five large tree planters with colored circles attached to them. The colored circles gave each object an easy reference point.

3. Procedure

The virtual space was an open plane with light green grass as a texture. The objects were centered 48 feet from the test participant. Two of the objects defined the spatial interval lying in a frontoparallel plane (the plane perpendicular to the line of sight that passes through the center of the spatial interval). These object were placed at 8, 10, or 12 feet apart from the center depending on the test sequence being conducted. The other two objects defined a spatial interval in depth (sagatti plane). These were also placed at 8, 10, or 12 foot intervals from the center. Test sequences were randomized, but all participants received three tests or training session for each distance group. Initial tests of participants were to gauge for current proficiency with distance estimation in all three distance intervals. Then the participants were taken inside for training in all three distance intervals. Finally participants were tested again in all three distance intervals to record the amount of improvement. The objects were brown in color and box-like in appearance, all measuring the same size (.11m x .11m x .41m)(Figure 17). All observers had a total of twenty-seven tests, which were conducted in a random order. In distance one, objects one, two, and three were 2.43 meters (8 feet) from the center point. In distance two the objects were set up 3.0 5 meters (10 feet) from center, and in distance three the objects were 3.66 meters (12 feet) (Figure 17). The participant was instructed to match the

distance of object one and three (frontoparallel plane) to objects two and four (sagatti plane) by moving object four. Each training condition was repeated three times, initial, training , and finial at the three distances, for three trials at each distance, for a total of twenty-seven trials.

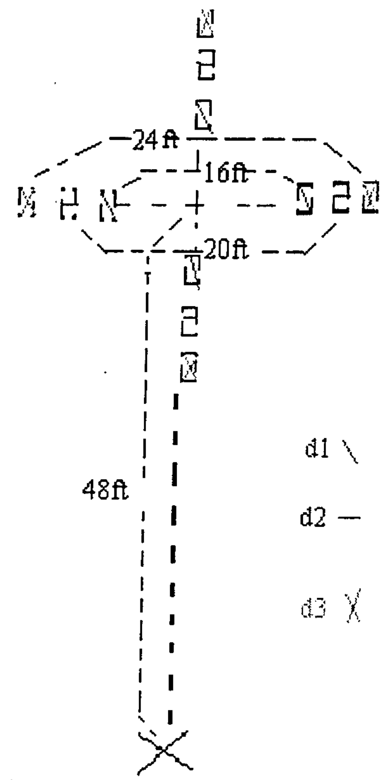

Figure 16. Setup for Experiment Five

The Cognitive task setup had five colored rings and distances: Red – Brown 18 feet, Red – Blue 43 feet, Red – Green 50 feet, Red – Yellow 31 feet, Brown – Blue 37 feet, Brown – Green 51 feet, Brown – Yellow 36 feet, Blue – Green 17 feet, Blue – Yellow 22 feet, Green – Yellow 21 feet (Figure 18). The participants viewed the objects from a second floor elevation(12 feet), at a distance of 61 feet from the green object. No subject looked for more than 20 seconds. Participants were told that they would need to

judge the distances between the objects. Participants were then led to an enclosed room and given colored rings in a random order, the same colors seen outside. They were then told to place the rings, on a blank paper, in the same spatial arrangement as viewed outside and then write the distances between the rings.

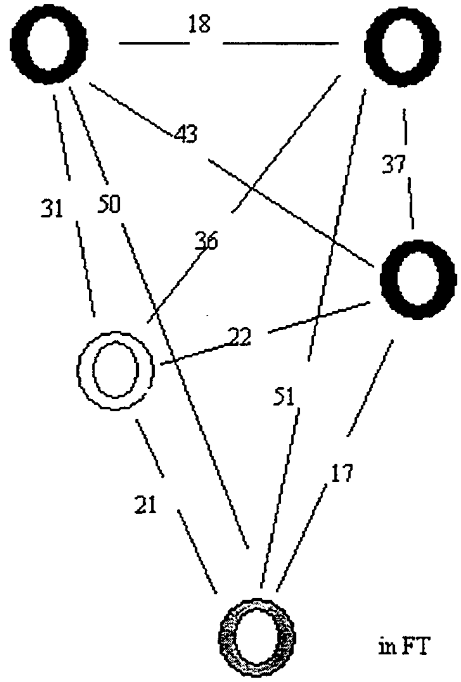

FIGURE 17. Cognitive Ring Setup

D. RESULTS

After all participants completed the tests, the data were converted from percentages of a foot to inches. For each test participant the amount of error and standard deviation were calculated for the initial test condition (Table 6) followed by the final test condition (Table 7). The plot of these values is shown in Figure eighteen. Finally the percent of error from the real distance was calculated (Table 8) and plotted (Figure 19).

Inches	Initial Test					
Subjects	Dist 1	Std Dev	Dist 2	Std Dev	Dist 3	Std Dev
1	128.67	13.42	156.00	35.56	178.67	33.55
2	144.67	48.08	44.00	62.48	128.33	81.85
3	56.17	8.58	69.00	4.58	87.00	3.00
4	67.67	11.67	87.67	14.29	83.00	3.00
5	27.00	3.46	40.50	21.65	50.66	11.01
6	22.00	16.09	73.66	29.16	56.66	22.50
7	43.66	24.58	40.00	21.70	38.66	17.04
9	60.33	17.89	69.00	17.06	53.66	1.53
10	26.50	21.39	28.66	6.66	38.00	19.69
11	110.33	7.23	94.33	24.17	136.33	32.47
12	65.66	8.50	65.33	8.32	104.00	22.33
13	51.33	8.62	44.66	22.74	72.33	12.58
14	12.66	11.93	43.66	21.73	29.66	28.67
15	129.66	10.78	116.00	25.51	139.16	24.69
16	134.50	9.26	131.00	26.62	139.33	23.07
17	93.66	25.54	73.00	22.51	125.66	10.21
18	103.00	1.00	150.00	37.16	134.00	39.94

Table 6. Experiment Five Initial Results

Inches	Final Test					
Subjects	Dist 1	Std Dev	Dist 2	Std Dev	Dist 3	Std Dev
1	76.83	19.34	97.67	8.50	57.50	69.32
2	23.33	23.09	18.00	15.72	2.67	3.78
3	9.67	10.01	10.00	4.36	12.33	3.78
4	21.33	6.80	38.00	24.84	34.33	8.38
5	25.33	22.33	22.33	7.77	55.00	23.38
6	19.00	11.26	49.00	10.14	26.33	16.80
7	9.00	9.16	13.33	9.07	24.66	8.32
9	20.00	1.00	42.33	35.79	43.33	20.60
10	15.00	7.00	35.66	13.79	47.33	17.50
11	41.00	49.38	51.66	16.07	101.00	27.18
12	72.00	5.56	38.00	12.12	74.00	26.62
13	12.00	9.00	30.33	25.32	15.00	3.60
14	12.66	13.57	32.66	21.38	17.66	10.97
15	42.66	15.04	46.00	29.01	63.00	23.38
16	12.66	16.74	17.33	8.38	25.33	7.63
17	24.33	4.51	12.33	9.50	40.00	9.85
18	54.00	38.57	49.33	3.78	75.66	30.66

Table 7. Experiment Five Final Test Results

Inches	Cog Test
Subjects	% Error
1	128.67
2	224.9
3	113.25
4	104.00
5	59.00
6	79.82
7	162.10
9	65.74
10	106.34
11	71.41
12	112.24
13	90.10
14	106.32
15	85.25
16	78.82
17	147.97
18	84.94

Table 8. Experiment Five Cognitive Results

The underlined participants in Tables six, seven, and eight indicate the participants that did particularly well in the organizational ring task.

E. DISCUSSION

The first hypothesis was to see if there was an effect between a cognitive task related to distance perception and real world distance estimation accuracy. From Figure eighteen there appears to be a strong connection between the cognitive task and the amount of improvement per subject. However, participants 5, 10, 11, 14, 16, and 17 were the only participants that did well in the cognitive task. Subject five, an exception to the rule, showing that a well organized person trains well (dark blue, light blue). The rest of the participants show the exact opposite.

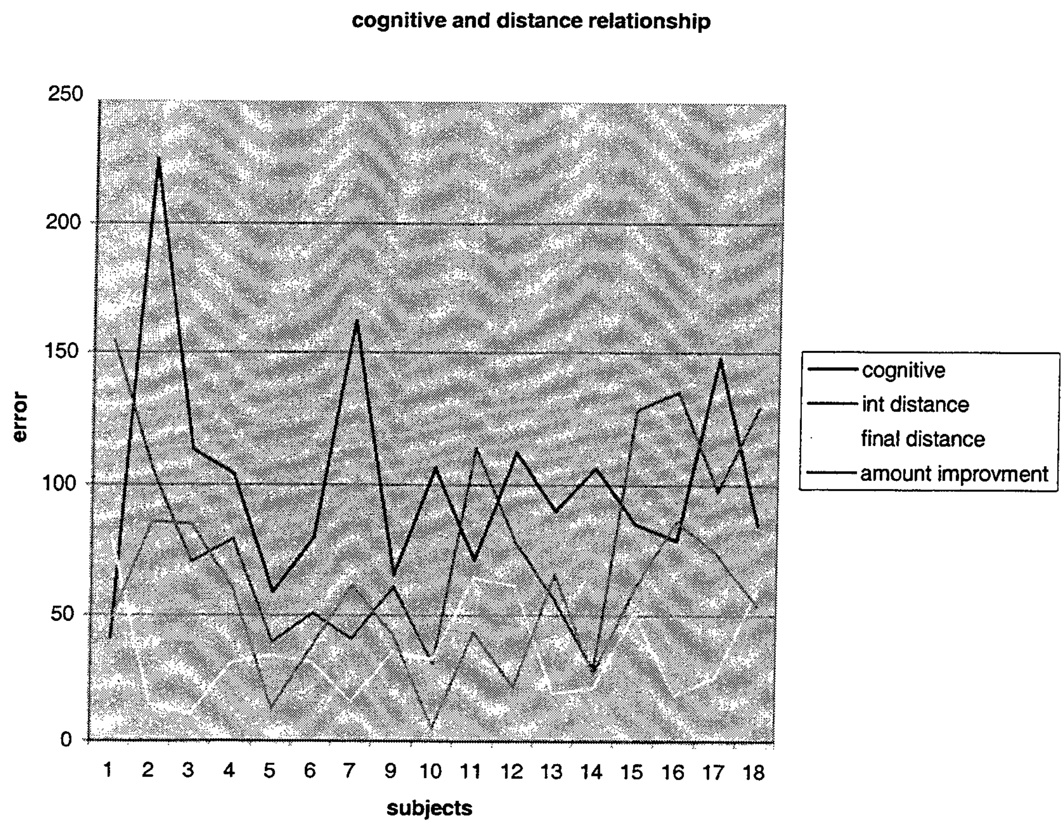

Figure 18. Participants Versus Error

The second hypothesis was to show that there exists a positive training relationship from virtual environment to increased real world performance. Figure nineteen gives the average amount of error in the training sequences: sequences one thru three, being initial tests before training (16 feet, 20 feet, 24 feet); sequences 4 thru 6 results after being trained. In all cases the average amount of error was reduced by a factor of two with the training.

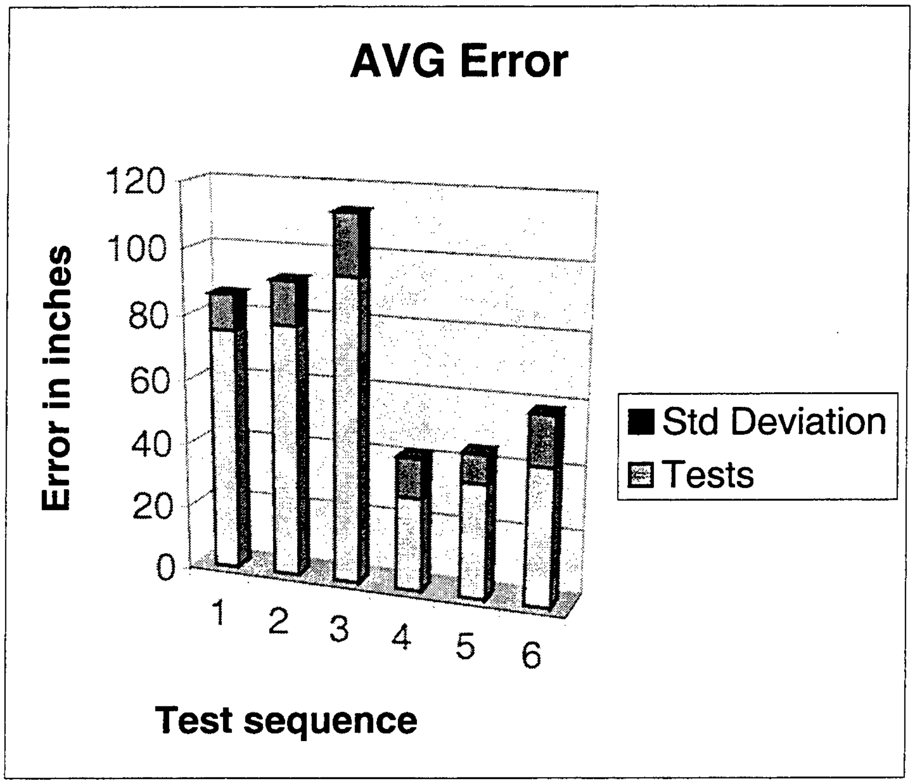

Figure 19. Test Sequence Versus Error

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VIII. CONCLUSIONS

A. EXPERIMENTAL DISCUSSIONS

Experiments one and five prove that as distance increases so does the average amount of error (Figures 4, 19). A problem that plagues all the experiments in this thesis was that the population size was too small. In order to smooth out the variance, and the t-test effectively, a large population is needed. Using the average amount of error for the test participants showed that an effective Virtual World can be built to train personnel (Figure 5).

Experiments two and three show that a perspective feedback technique works better than metric feedback (Figures 8,20). Also they show that there was only a slight increase in how well the perspective participants did over the metric; therefore, it is recommended to use both until further work can be done in this area. After three training periods, participant's accuracy was best. The fourth session did not increase accuracy of estimations, however, through out the week, there was a net positive improvement (Figure 13), and that a two week metric for training retention was not long enough to see any skill degradation (Figure 8).

The graph from experiment four shows that the optimal setting for a 60-degree head mounted display is a horizontal setting somewhere between 30 and 60 degrees (Figure 15), which was later confirmed by the manufacturer to be 48 degrees.

Experiment five shows that a person who organized well with the ring matching task, does not always transfer distance perception information from the virtual world to the real world, as a person that did not do well in ring matching (Figure 18).

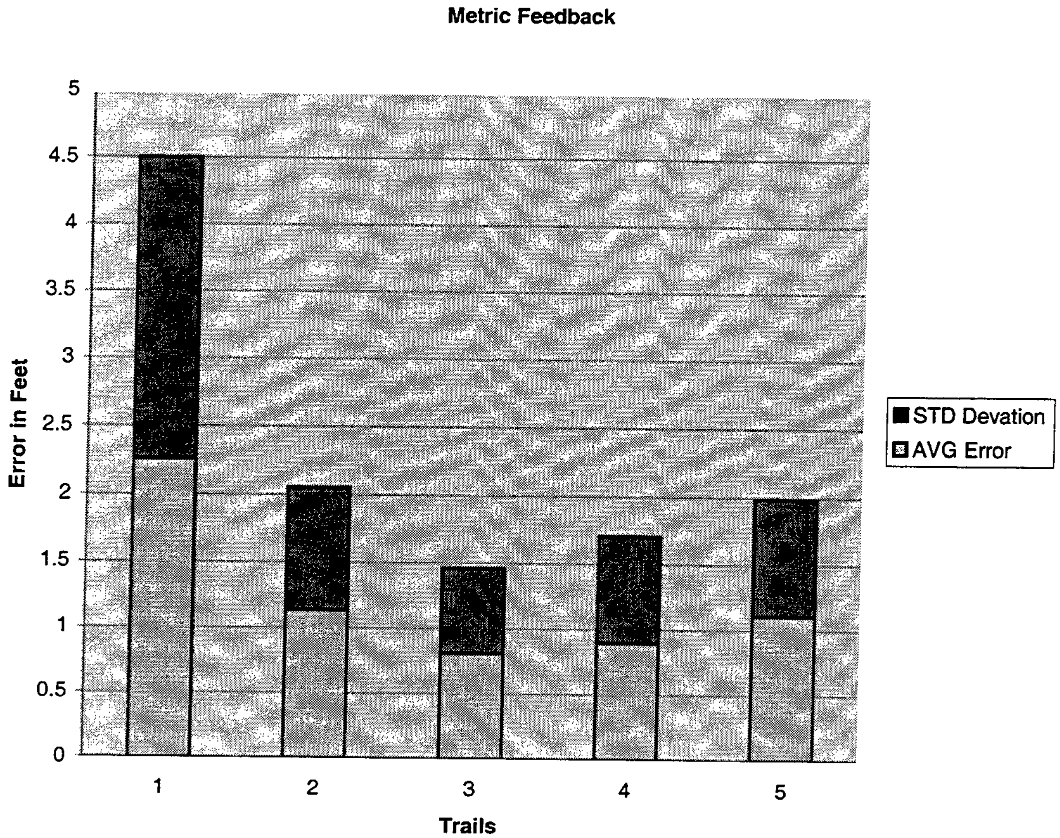

Figure 20. Error Versus Trial Number

B. FUTURE WORK

As referred to earlier, any one of these experiments can be rerun with a larger population size. There needs to be an intermediate distance test run, to look at the slope of the error increasing as distance increases.

More work needs to be done with experiment five to produce results that would lead to a better list of prescreening traits that would be sensitive to distance estimation skill. The cognitive task from experiment five can be used as a initial test to gauge how well a subject can perceive distances. The subject can then be run through the training routine and tested again in a similar setup as the cognitive test. This would open up the

possibility of investigating unrelated tasks both dealing with depth perception to see if the training had an across the board effect on distance perception not just limited to this specific task.

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LIST OF REFERENCES

Alfano, Patricia L. and George F. Michel. (1990). Restricting the Field of View: Perceptual and Performance Effects. Perceptual and Motor Skills, Vol. 70, No. 1, pp. 35-45.

Bliss, J.P., Tidwell, P.D., and Guest, M.A. (1997). The Effectiveness of Virtual Reality for Administering Spatial Navigation Training to Firefighters. Presence, 6, 73-86.

Capps, Michel, MOVES Academic Group, Naval Postgraduate School, Monterey, CA: http://www.cs.nps.navy.mil/people/faculty/capps

Crvarich, (1999) An Exploration of Techniques to Improve Relative Distance Judgments within an Exocentric Display, Unpublished Masters Thesis, pg 3. http://www.hitl.washington.edu/publications/crvarich/1.html

Darken, R.P. & Banker, W.P. (1998). Navigating in Natural Environments: A Virtual Environment Training Transfer Study. Proceedings of VRAIS '98, 12-19.

Ellis, S. R., Menges, B. M., Jacoby, R. H. , Adelstien, B.D. ,and McCandles, J. D. , (1997) Influence of Head Motion on the Judged Distance of Monocular Presented Virtual Objects. Proceeding of the Human Factors and Ergonomics Society 41st Annual Meeting, 41, 1234-1238.

Gozel R. (1998) Distance Perception in Virtual Environments: Effects of Texture, Pattern and Target Location on the Accuracy of Distance Estimation. Unpublished Manuscript, Naval Postgraduate School, Monterey, CA.

Hamilton, Lawrence C. (1992). A Second Course in Applied Statistics. New York: McGraw-Hill.

Henry, D., and Furness, T. (1993). Spatial Perception in Virtual Environments: Evaluating an Architectural Application. Virtual Reality Annual International Symposium, 1993 IEEE, 33-40.

Hodges, F. Larry, Georgia Institute of Tech:
http://www.gvti.org/

James, K.R. and Caird, J.K. (1995). The Effect of Optic Flow, Proprioception, and Texture on Novice Locomotion in Virtual Environments. Proceeding of the Human Factors and Ergonomics Society 39th Annual Meeting, 275-279.

Lampton, D. R., McDonald, D. P., and Singer, M., (1995) Distance Estimation in Virtual Environments. Proceeding of the Human Factors and Ergonomics Society 39th Annual Meeting, 39, 1268-1272.

Loomis, J. M., Da Silva, J. A., Philbeck, J. W. and Fuksima, S. S., (1996). Visual Perception of the Location and Distance, Current Directions in Psychological Science, 5(3), 72-77.

McAllister, F. David, Stereo Computer Graphics, PRINCETON UNIVERSITY PRESS Princeton, New Jersey 1993 Princeton University Press.

Montello, D. R., (1991). The Measure of Cognitive Distance: Methods and Construct Validity. Journal of Environmental Psychology, 11, 101-122.

Multimedia Laboratory Department of Computer Science North Carolina State University: http://www.multimedia.ncsu.edu

Roscoe, S. N., (1984). Judgments of Size and Distance with Imaging Displays, Human Factors, 26, (6), 617-629.

Seidel, R.J., Chatelier, P.R., (1997). Virtual Reality, Training's Future? Perspectives on Virtual Reality and Related Emerging Technologies. New York: Plenum Press.

Sinai, M.J., Krebs, W.K., Darken, R.P., Rowland, J. H., and McCarley, J.S. (1999). Egocentric Distance Perception in a Virtual Environment using a Perceptual Matching Task. Proceedings of the 43rd Annual Meeting Human Factors and Ergonomics Society, 43, 1256-1260.

Sinai, M. J., Ooi T. L., He J. Z., (1998) Terrain Influences the Accurate Judgment of Distance, Nature, Vol 395.

Steven, S. S., (1975). Psychophysics: Introduction to its Perceptual, Neural, and Social Prospects. New York: Wiley.

Unknown author posted on Internet. (1999): http://home.pacifier.com

Wagner, M., (1985). The Metric of Visual Space. Perception and Psychophysics 38(6), 483-495.

Waller, D., Hunt, E., and Knapp, D. (1998). The Transfer of Spatial Knowledge in Virtual Environment Training. Presence, 7, 129-143.

Waller, D., Miller, J. (1998). A Desktop Environment Trainer Provides Superior Retention of a Spatial Assembly Skill. Proceeding of the Human Factors conference on CHI 98 summary: Human Factors in Computing Systems. 339.

Winn, W. D. (1998). Virtual Environments for Maintenance Training, Kallmeyer'sche Verlagsbuchhandlung, 327-350.

Witmer, B.G., Bailey, J.H., Knerr, B.W., and Parsons, K.C. (1996). Virtual Spaces and Real-World Places: Transfer of Route Knowledge. International Journal of Human-Computer Studies, 45, 413-428.

Witmer, B. G., and Kline, P., (1998). Judging Perceived and Traversed Distance in Virtual Environments. Presence, 7, 144-167.

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